ALS BOOSTER RING RF SYSTEM UPGRADE FOR TOP-OFF MODE OF OPERATION

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Abstract

Advanced Light Source (ALS) is one of the first 3rd-generation synchrotron light sources and it has been in operation at the Berkeley Lab since 1993. In the present ALS operation scenario, 1.5GeV electron beam is injected from the booster into the storage ring every 8 hours where it is accelerated to the final energy of 1.9GeV. The beam decays between fills from 400mA to 200mA with the time average current of 250mA. In order to increase beam brightness the ALS team plans to increase the beam current to 500mA and maintain it constant during machine operation ("Top-Off" mode of operation). This operation scenario will require full energy injection from the booster ring into the storage ring and constant operation of the injector (10 bunches with the total charge of 1nC every 30-35 second). In this paper we will present the results of the ALS injector RF system analysis for Top-Off mode of operation and describe the way we intend to implement the necessary modifications to the booster RF system.

INTRODUCTION

The current ALS Booster RF system operates at 499.644 MHz and uses a single room temperature re-entrant RF cavity identical to those used in the ALS Storage Ring. The cavity is powered by a modified 15kW commercial UHF transmitter. Tuning of the RF cavity is achieved by the movement of the metallic cylinder, driven by a stepping motor, in or out of the cavity. The Booster cycles at 1Hz, each cycle consisting of a 350ms accelerating ramp and a 650ms recovery/quiescent period. The tuner control loop is enabled only during quiescent period of the Booster cycle. In the current injection scenario, the booster ring accepts three 50 MeV (8ns apart) electron bunches from ALS drift tube traveling wave injection linac and accelerates them to 1.5GeV. The booster RF cavity cell power changes from 80W at the injection to 7kW at the end of the accelerating cycle. The average ALS booster beam current is 4mA (1nC total beam charge).

BOOSTER RF SYSTEM POWER REQUIREMENTS

In the top-off mode of operation the Booster RF system has to accelerate the electron beam up to the full ALS storage ring energy (1.9GeV). The dominant mechanism, which dictates the minimum required RF bucket height for ALS Booster top-off mode operation is the quantum
emission of energetic photons by the electron beam (quantum lifetime). According to Sands [1] the quantum lifetime is given by the following formula:

$$\tau_q = \frac{\tau_e}{\eta_\sigma^2} \exp(\frac{\eta_\sigma^2}{2}) \qquad (1)$$

where: τ_q - quantum lifetime
τ_e - longitudinal damping time

$$\eta_\sigma = \frac{relative \cdot bucket.(half) \cdot height}{relative \cdot energy \cdot spread} \qquad (2)$$

Table 1 shows the quantum lifetime, synchrotron tune, cavity cell power and effective ALS Booster cavity voltage as a function of η_σ parameter for 1.9GeV electron beam energy.

Table 1: Quantum Lifetime & Synchrotron tune per cell power.

η_σ	Quantum Lifetime	Synchrotron Tune	Cavity Cell Power	Effective Cavity Voltage
-	[s]	-	[kW]	[kV]
3	0.017	0.0120	19.0	436
3.5	0.065	0.0129	22.8	477
4	0.319	0.0137	27.3	522
4.5	2.14	0.0146	32.8	573
5	18.8	0.0155	39.3	627
5.5	216.2	0.0164	47.0	686
6	3203	0.0172	56.0	748
6.5	61373	0.0181	66.5	815
7	1600000	0.019	78.9	888

To allow for ALS Booster ring stand-alone operation as a storage ring, the RF source should be able to output at least 75 kV of RF power.

BEAM LOADING EFFECT IN ALS 50 MEV LINAC STRUCTURE.

For optimally tuned beam injection system the beam loading effect in the linac structure is the main factor responsible for the bunch to bunch energy spread of the beam captured by the ALS booster RF system. This factor will determine the minimum allowed booster RF bucket height during beam capture period. In the ALS top-off operation mode to insure more uniform storage ring beam pattern we plan to deliver 10 bunches to the ALS storage ring in each injection cycle.

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The ALS linac has uniform parameters along its length since it is a constant impedance structure. The filling time for a constant impedance structure is:

$$T_f = \frac{L}{v_g} = \tau \cdot \left(\frac{2 \cdot Q}{\omega} \right) = 393\text{ns} \quad (3)$$

where: L - length of linac section (2m)
v_g - energy flow velocity
τ - attenuation parameter (0.285/2m section)
Q - linac structure quality factor (Q=13000)
ω - operational frequency: (ω=2*π*2.998GHz)

Since the filling time of the linac accelerating structure is much longer than the bunch spacing (393ns>>8ns), for analysis of the beam-cavity interaction the beam could be represented as a dc pulse with the pulse length equal to the length of the bunch train. The formula for the beam induced voltage in the traveling wave linac structure has been developed by P.B. Wilson [2]:

$$V_b(x) = I_0 \cdot r_{sh} \cdot L \left[\left(1 - \frac{1}{\tau}\right) \cdot \left(1 - e^{-\tau \cdot x}\right) + x \cdot e^{-\tau \cdot x} \right] \quad (4)$$

where: x - bunch length parameter: x=t/Tf
t - length of the bunch train.
$V_b(x)$ - beam induced voltage.
I_0 - linac beam current.
r_{sh} - linac shunt impedance (53MΩ/m).

For proposed multi-bunch operation with ten bunches the total charge per shot is $Q_{tot}=1e^{-9}$[Q]. Given Io=13.9[mA], t=72[ns], x=0.183; τ*x=0.0522 the total energy spread: σE = 136 keV or σE/E = 0.27%.

The conclusion reached is that the beam loading effect in ALS LINAC injector is not a significant problem for the proposed top-off mode of operation.

BOOSTER RF RAMP SCENARIO

Coupling between transverse and longitudinal oscillations gives rise to excitation of resonances for tunes which satisfy the following equation [3]:

$$k \cdot Q_x + l \cdot Q_y + m \cdot Q_s = n \quad (5)$$

where: Q_x, Q_y and Q_s are horizontal, vertical and synchrotron tune values respectively with k, l, m, n integers.

For the given booster ring lattice parameters, the horizontal and vertical tunes are constant. From a logical point of view, the simplest way to avoid synchro-betatron resonance problems is to choose the optimum booster ring operation conditions and maintain the synchrotron tune value constant during booster energy ramp. Booster RF parameters for proposed ramp (constant synchrotron tune value) are presented in Table 2. Calculations were done for 4mA (1nC total beam charge) booster current, cavity-to-power source coupling factor β_c=2 (cavity tune into the resonance prior to beam injection).

Table 2: Booster parameters for constant synchrotron tune.

Beam Energy	Synchr. Tune	RF Cell Power	Dynamic Bucket Half Height	Cavity Voltage	Synchrotron Radiation losses
MeV	-	kW	keV	kV	keV
50	0.0181	0.054	340	20.2	.000133
100	0.0181	0.175	689	39.9	0.0021
200	0.0181	0.67	1403	80.8	0.034
300	0.0181	1.5	2116	121.8	0.172
400	0.0181	2.6	2808	160.7	0.544
500	0.0181	4.1	3516	202.1	1.33
600	0.0181	5.9	4208	242.5	2.76
700	0.0181	8.0	4882	282.5	5.1
800	0.0181	10.5	5550	323.8	8.7
900	0.0181	13.3	6190	364.5	14.0
1000	0.0181	16.2	6775	402.3	21.3
1100	0.0181	19.7	7356	443.7	31.2
1200	0.0181	23.8	7919	487.7	44.1
1300	0.0181	27.7	8378	526.1	60.8
1400	0.0181	32.4	8818	569.1	81.7
1500	0.0181	37.5	9189	612.2	107.7
1600	0.0181	44.0	9558	663.2	139.5
1700	0.0181	50.0	9759	707.0	177.7
1800	0.0181	58.0	9968	761.5	233.4
1900	0.0181	66.0	10018	812.3	277.3

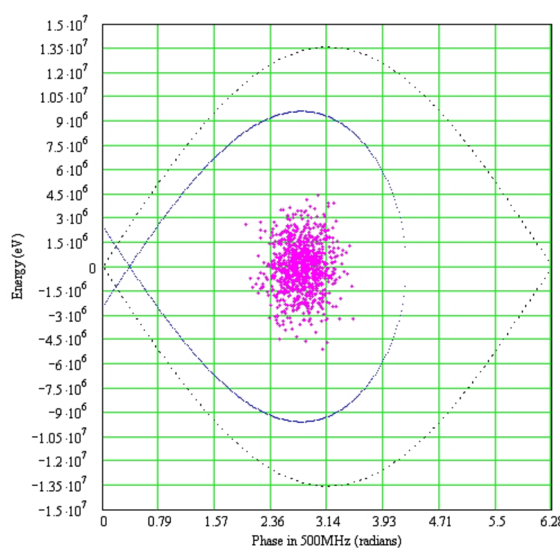

Figure 1: Stationary & Dynamic 1.9GeV Booster RF buckets for 66kW cell power.

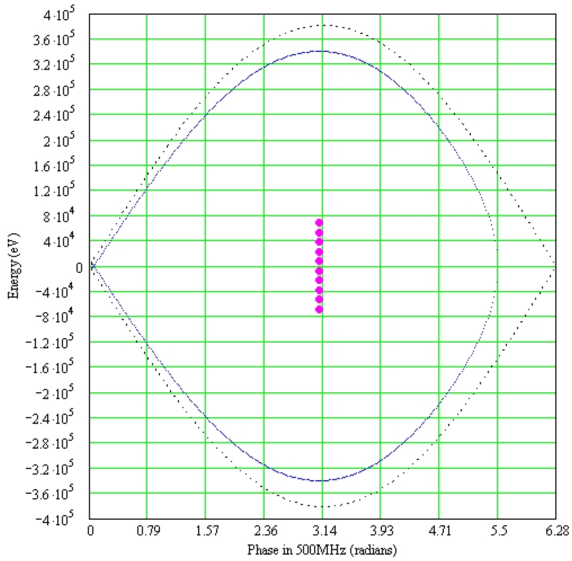

Figure 2: 10 Linac bunches captured by 54W RF bucket.

The stationary and dynamic 1.9GeV ALS Booster RF buckets for 66 kW cavity cell power and the single bunch with the population of 1000 electrons with normal energy distribution is shown in Figure 1. Figure 2 shows 10 linac bunches with the total energy spread of 136keV captured by 54W booster RF bucket (the energy spread inside each linac micro bunch is neglected). The difference between the static and dynamic buckets in this case is the result of the cavity detuning due to the beam loading effect.

BOOSTER RF SYSTEM

Final Amplifier/Transmitter

The existing final amplifier–transmitter can not produce the output power needed, so we plan to replace it with a higher output power final amplifier-transmitter based on an inductive output tube (IOT). The IOT based amplifier was chosen over retro-fitting a higher power klystron or IOT due to the cost of modifications to the existing transmitter and the short installation schedule. Additionally, the broadcast industry has largely switched over to IOTs from klystrons so future development and support for klystrons in this frequency and power range will be minimal compared to that for IOTs. A new regulated linear dry-type HVPS will be necessary to support the new final amplifier.

Control System

The new transmitter will include either an embedded micro-controller or PLC that will control and monitor all transmitter parameters. The embedded controller will have either a ModBUS/TCP interface that the ALS Controls Group will use to program an interface to the EPICS system or the embedded controller will be interfaced to EPICS by the transmitter manufacturer and delivered as a turn-key EPICS controlled high power amplifier/transmitter.

Transmission System & RF Coupling Window

The existing transmission line, comprised of mixture of rigid line, clamp line, 3” air dielectric Heliax, 3 1/8” to 6 1/8” coaxial adapters, and WR1800 (for interfacing to the cavity) will be replaced with 4 1/16”, 6 1/8”, and WR1800 to handle the increased average power for Top-Off operation. We plan to re-use the 75kW 6 1/8” circulator but upgrade the reject and transmitter test loads to >80kW water loads and add a motorized wave guide switch to select between the test load and Booster Ring cavity.

CONCLUSION

The analysis of the injection system has shown that no significant problems lie ahead. The synchrotron tune can be held effectively constant during the energy ramp thus minimizing the probability of potential problems with synchro-betatron instabilities. Favorable quantum lifetime can easily be achieved with the increased output power capabilities of the upgraded RF system. The Top-Off project was funded with a start date of March 1, 2005 with completion of the equipment installation in spring/summer 2006. Top-Off operation will follow later in the year as systems are commissioned.

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